Glacial erosion: No stones unturned?

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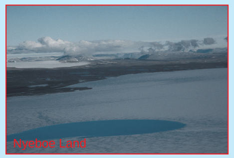
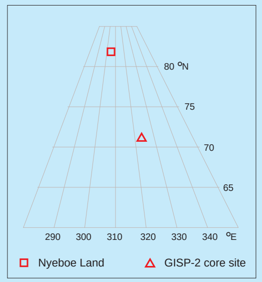
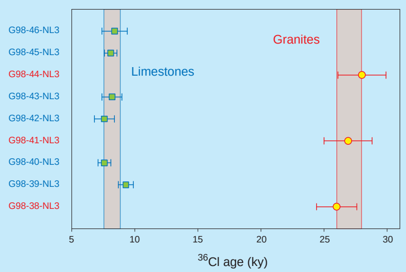
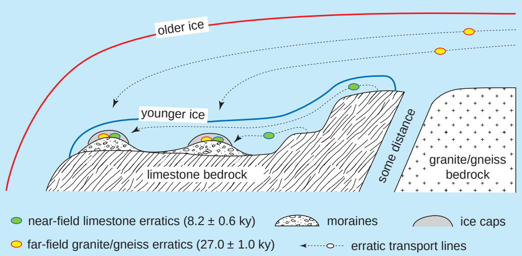






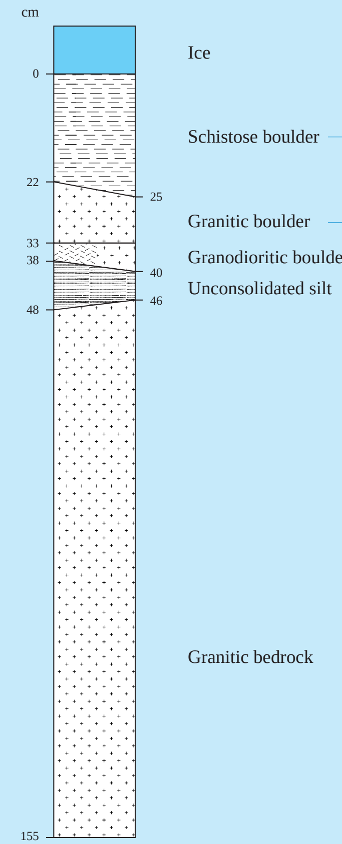


ABSTRACT

Is erosion of landscape under ice sheets significant or negligible? In the Arctic, it seems, it is both. I show evidence for cold-based (non-eroding) margins of Greenland ice during the Last Glacial Maximum (**left side**) and for warm-based (eroding) center at an unspecified time in the past (**right side**).

Take a walk through Nyeboe Land, in the northwestern Greenland (**map** and **photographs**), and, as your feet sink in the soft till, your eyes are drawn to the mountains across the Nares Strait or to the margin of the Greenland ice sheet. But one of the most remarkable features in this landscape is one of the easiest to overlook - that this surface has two generations of erratics deposited at two different times. These erratics were dated by cosmogenic ^{36}Cl (half-life of 301 ky; ky = 1000 years). One group of boulders, exclusively red granites, has and average exposure age of 27.0±1.0 ky; the other, exclusively gray limestones, has and age of 8.2±0.6 ky (**graph**). The small spread of boulder ages within each group shows that these erratics have remained in the same position since their deposition. And the age difference suggests that there were two ice-sheet advances (**diagram**): the first involved a large, regional ice and wide dispersal of granitic erratics from the interior of Greenland; the second glaciation was smaller and dispersed material from the local bedrock. The preservation of the older generation of erratics is attributed to the younger ice being cold-based, and thus having a negligible eroding power. Similar landscapes that contain well-preserved older material are common in the High Arctic, suggesting that ice margins were often cold-based. This is in accord with botanical evidence showing that fragile plants can be preserved under inundating ice and exposed undestroyed centuries later (Bergsma et al., 1984, Entombed plant communities released by a retreating glacier at central Ellesmere Island, Canada. *Arctic* 37, 49-52).

But evidence of high erosive power of Arctic ice sheets also exists. In the most unexpected place - under the cover of 3 km of ice, at the supposed ice divide, in the center of the Greenland Ice Sheet (**map**). Samples of rocks at the base of the GISP-2 ice core were obtained (stratigraphic **profile**) and three cosmogenic nuclides were measured: ^{36}Cl (half-life of 301 ky), ^{10}Be (half-life of 1500 ky) and ^{21}Ne (stable). We expected that these nuclides, taken together, could be used to determine the last time when the bedrock was free of ice. This can be accomplished, at least in theory, using the technique called 'burial dating', in which a difference in the inventories of nuclides with different half-lives is analyzed. But our rock samples yielded zero concentration of each nuclide! A near impossibility, since ^{21}Ne is a stable nuclide, and its concentration is not diminished by spontaneous radioactive decay. This absence of any cosmogenic signature in the bedrock strongly suggests that any previously accumulated cosmogenic nuclide inventory was removed by ice, thereby indicating eroding, possibly warm-based ice in the center of the Greenland Ice Sheet. This result is in line with geochemical evidence from the same location indicating local erosion of the granitic bedrock (Weis et al., 1997, Ice sheet development in Central Greenland: implications from the Nd, Sr and Pb isotopic compositions of basal material. *Earth and Planetary Science Letters* 150, 161-169).



Cosmogenic results	Source
$^{36}Cl/Cl = 0±13 * 10^{-15}$	DE
$^{36}Cl/Cl = 0±5 * 10^{-15}$	DE
$^{10}Be/Be$ = ~ blank	JK
^{21}Ne = ~ blank	KM

Sources of isotopic data:

DE: David Elmore, Purdue University, 1995
JK: Jeff Klein, University of Pennsylvania, personal communication, 1995
KM: Kurt Marti, University of California at San Diego, personal communication, 1996

$^{36}Cl/Cl$ after subtraction of the radiogenic component

Hypotheses tested:

(1) Ice sheet is very old and any previously accumulated ^{36}Cl and ^{10}Be has decayed. But because the stable ^{21}Ne is also zero, this hypothesis must be rejected.

(2) Last ice free period was too short for measurable amounts of cosmogenic nuclides to accumulate. This hypothesis cannot be rejected. If true, this scenario would have important implications for the early history of the Greenland Ice Sheet.

(3) Bedrock under ice sheet has been eroded and any previously accumulated cosmogenic isotopes have been removed. This hypothesis cannot be rejected by the cosmogenic data.

(4) Any combination of the above. This hypothesis must be rejected based on hypothesis 1 above. But a combination of short exposure time (hypothesis 2) and erosion (hypothesis 3) is possible.

Conclusion: erosion (by a warm-based ice?) is the most likely explanation of the low cosmogenic inventories in rocks beneath the GISP-2 site.

Research supported by the US National Science Foundation (Arctic Natural Sciences Program) and by the David and Lucile Packard Foundation. Field logistics provided by the Polar Continental Shelf Project (Canada). Special thanks to Jeff Klein, University of Pennsylvania, for measuring ^{10}Be and to Kurt Marti, University of California at San Diego, for measuring ^{21}Ne.